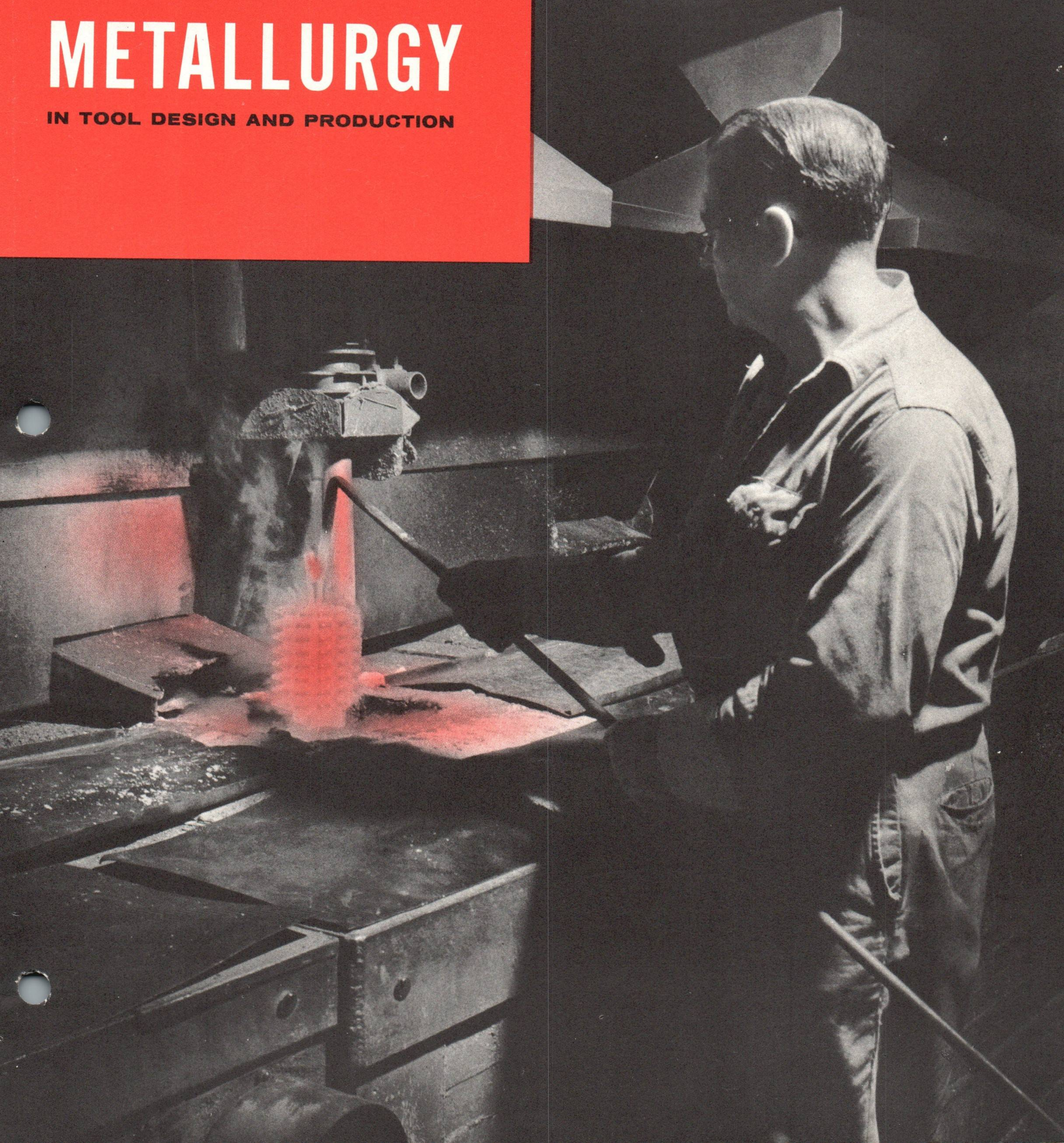
ILLINOIS TOOL WORKS
TOOL & INSTRUMENT DIVISION
CHICAGO

METALLURGY

IN TOOL DESIGN AND PRODUCTION



foreword

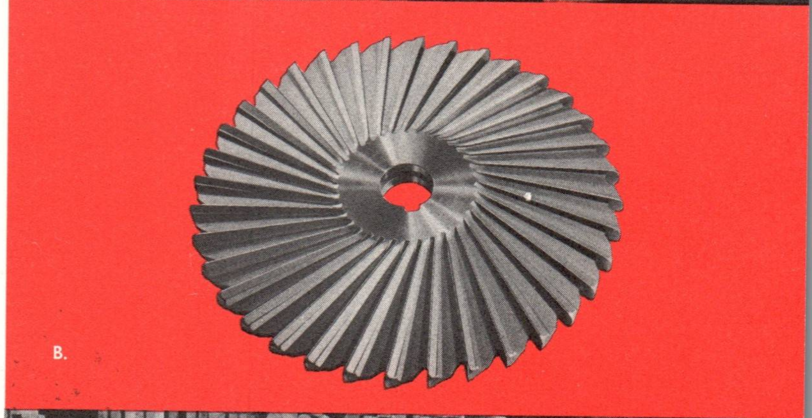
In the design and production of metal cutting tools, metallurgy at Illinois Tool Works is considered the prime ingredient. Management's philosophy is that no single element of metal cutting tool production is as important as metallurgy, because material expertly selected, forged and heat treated is the heart of the tool. This philosophy dates back to the company's active role in the formation of the "American Society for Metals." Arthur Henry, plant metallurgist in those days was a founder member, and in fact, the society housed its early business activities in office space supplied by the company. Time has not changed this philosophy.

This booklet is intended to show the present day place of metallurgy in the production of fine cutting tools at Illinois Tool Works. It is especially timely because of the rapid pace of change during the last few years. With these changes has come the challenge of filling new needs. This practical discussion of the strides in metallurgical advancements to secure full-performing, long-lived cutting tools is supplemented by helpful hints for the Tool Engineer, all for the purpose of helping in the selection and operation of cutting tools for lowest possible machining cost.

The development of new materials for aircraft, missiles, jet engines, nuclear power plants and improved electronic and commercial products has been extremely rapid. Today, to name only a few, cutting tools are needed for Titanium alloys, High Temperature alloys, new Stainless Steels and pure metals such as Zirconium, Uranium, Tungsten and Molybdenum. In addition many alloy steels are being machined at high hardness levels un-dreamed of only a short time ago.

These demands require the best in cutting tools and Illinois Tool Works not only has the experience necessary to recommend the proper tool material, but also the "know-how" to provide the best in design, metallurgy and workmanship.

A.



B.

C.

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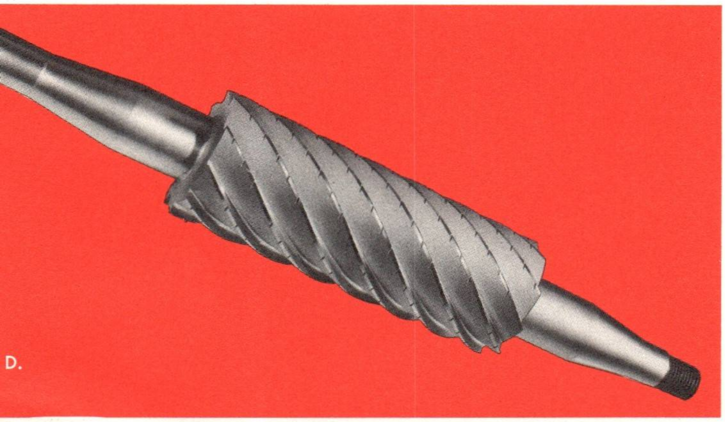
Three basic factors are vitally important to maximum performance of any metal cutting tool—proper design, precision manufacture and the best tool material characteristics for a specific application. The first two of these factors are tangible from the viewpoint of the tool user. They can be blueprinted, measured and checked against actual requirements. The third factor, on the other hand—best material characteristics—cannot be effectively evaluated by the tool user. He must rely on the tool manufacturer in this regard because the variables and their relationship to each other are more difficult to pinpoint, and because specialized facilities and skills are required for testing and evaluating tool material characteristics. More importantly, to adequately inspect a finished tool for metallurgical qualities, the tool would have to be destroyed. More than ever then, the tool user is forced to rely on the reputation and integrity of his supplier.

Cost conscious tool users realize the importance of tool material selection and metallurgical processing, and appreciate the careful attention these receive at Illinois Tool Works.

Their confidence is reflected in the high level of "exact repeat" orders for special cutting tools, that the company enjoys.



D.

A. A test coupon from every billet of steel to be used by Illinois Tool Works is carefully inspected.

B. 16" diameter cutter for sweep milling impeller blades on jet engine sections. Side teeth cutting edges run nearly to the hole, requiring considerable work under the hammer to provide desirable flow lines along the full length of the cutting edge.

C. Photo illustrates small portion of the wide variety of types and shapes of H.S.S. kept in Illinois Tool Works stock, permitting precise material selection for each job.

D. 8" diameter, 36" overall length slab mill with integral H.S.S. arbor. Billet required considerable working under the hammer as well as carefully controlled heat treatment to obtain uniform material consistency and hardness.

MATERIAL SELECTION — Tool metallurgy actually begins in the steel producing plant. There, continuing research in the metallurgical laboratories leads to the development of new and better steels. There too, precise alloying procedures are carried out to achieve steels which will meet rigid chemical and physical requirements. And, in addition, every heat is carefully inspected for conformity to Illinois Tool Works specifications before it leaves the mill.

Metallurgy at the mill, however, is only the first step in the sequence that finally assures the best possible steel in every Illinite cutting tool.

Before a given heat of high speed steel is accepted for fabrication, test coupons from every billet are subjected to thorough examination. Years of highly specialized experience have shown that, even within the limits of rigid basic material specifications, there are small variations which will affect the method of processing and the final performance of the tool. In addition, experience gained through many years of handling high speed steel is necessary to select the best source for each specific type, and even for certain sizes of steel. All high speed steel billets in the popular grades are purchased by Illinois Tool Works in complete heats—a procedure made possible by large volume requirements to assure absolute uniformity of the finished tools.

Experience gained through years of fabricating nearly every type of cutting tool, from nearly every type of material, plays an important part in selecting the specific type of steel for a given tool. Many companies require that material specifications be included on the tracing when a tool is designed. But there are so many different analyses of high speed steel offered commercially that selection by the tool user is sometimes difficult. This is especially true when a new material is to be machined and the tool engineer has insufficient production experience with similar tooling under similar operating and work piece conditions. In this case either an inadequate choice may be made or a too expensive choice may result. For this reason it is good practice to describe the work material and the operation in sufficient detail to enable Illinois Tool Works metallurgists and engineers to recommend the proper cutting tool material.

PREMIUM VS. GENERAL PURPOSE H.S.S.—It is false economy to purchase tools of general purpose analyses when the use of a special grade would more than pay for the added initial cost. It is equally wasteful to use a special analysis when a less costly grade would perform as well. It should not be forgotten that high quality general purpose steels such as M-1, M-2, M-7 and M-10 used in cutters of the proper design and properly applied, will do a very satisfactory job from the standpoint of overall cost in many tough applications. These general purpose grades of high speed steel have excellent edge toughness and a good balance of physical properties. There comes a point, however, in the severity of the application where the higher alloy (premium) grades are necessary. Tool users are invited to discuss such possible applications with ITW Tool Engineers to avoid unnecessary and sometimes unwise specification of the more costly high speed steels. Expensive Cobalt steels, for example, are sometimes specified without regard to the necessity. Cutting tools taking small, discrete chips in open cuts may need a higher Vanadium steel to improve their abrasion resistance. Cutting tools taking a heavy, continuous chip, or which are buried deep in a cut where cooling and lubrication is lacking, or which are subject to heavy rubbing pressures, will require a Cobalt analysis.

Each year the percentage of premium high alloy high speed steel used by Illinois Tool Works has increased due to the demand for better performance from cutting tools in existing applications. In addition there is a steadily increasing number of cases where only the high alloy grades will cut the high Rockwell, tough and abrasive new materials.

Two of the premium high speed steels which have proved very satisfactory on more severe applications are M-3 and T-15. Their place in cutting tool applications is recognized to the extent that Illinois Tool Works now carries in stock certain standard tools made from M-3 and T-15.

The use of such tools is justified:

1—To secure longer cutter life at the same speeds on conventional work materials.

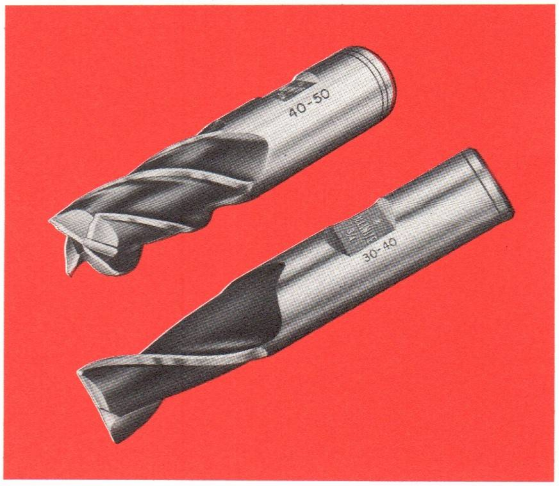
2—To increase cutting speeds (and hence productive rate) on conventional work materials.

3—To machine materials not possible to machine with general purpose high speed steels.

Illinois Tool Works has an inquiring viewpoint toward new metallurgical developments. There is never a time when active in-plant or customer test programs are not in progress. Such developments as Vacuum-melt high speed steel or new analyses are promptly investigated. In addition, ITW is always willing to co-operate with customers who wish to undertake test programs of their own to evaluate steels or surface treatments under specific operating conditions.

Table 1, page 5 shows the Molybdenum and Tungsten series of high speed steels. M-1, M-2, M-7 and M-10 are all widely used analyses. Although the first two represent the highest volume, all four are considered general purpose grades and they satisfy most metal cutting tool requirements. T-1, which was for many years the standard general purpose high speed steel, has been largely superseded by the Molybdenum grades mentioned. Today the acceptance of the Molybdenum types is so complete that the low volume usage of T-1 in cutting tools has resulted in occasional difficulty in securing the desired form or size on short delivery. Availability is naturally related to the demand, however, availability is not as much a problem at ITW since special sizes and shapes can be forged from billet stock on its own equipment.

The apparent contradiction in listing under the Molybdenum series a steel like M-3 which has more Tungsten than Molybdenum is explained by the fact that Molybdenum (atomic weight 96.0) is twice as effective as an equivalent percentage of Tungsten (atomic weight 184.0). Therefore, any high speed steel having a Molybdenum content 50% or more of the Tungsten content is classed as a Molybdenum type.



E. Premium alloyed standard tools for tough-to-cut material applications are available from distributor stocks.

NOMINAL ANALYSES OF HIGH SPEED STEELS

Molybdenum Series	Analysis (Percent)					Notes
Symbol	Molybdenum	Chromium	Vanadium	Tungsten	Cobalt	
M-1	8.50	4.00	1.00	1.50		
M-2	5.00	4.00	2.00	6.00		
M-3 Type 1	6.00	4.00	2.40	6.00		
M-3 Type 2	6.00	4.00	3.00	6.00		
M-4	4.50	4.50	4.00	5.50		
M-6	5.00	4.50	1.50	4.00	12.00	
M-7	8.75	4.00	2.00	1.75		
M-8	4.50	4.25	1.50	5.50		1.25 Columbium
M-10	8.00	4.00	2.00			
M-11	8.50	8.25	1.50		3.50	
M-15	3.00	4.75	5.00	6.75	5.00	
M-20	8.00	5.00	1.00		2.50	Boron Added
M-30	8.00	4.00	1.00	2.00	5.00	
M-33	9.00-9.50	4.00	1.00-1.20	2.00	8.00-9.00	
M-34	8.50	4.00	2.00	2.00	8.00	
M-35	5.00	4.00	2.00	6.00	5.00	
M-36	6.00	4.00	2.00	6.00	8.00	
M-38	5.00	4.00	3.00	6.50	9.00	
M-40	8.00	4.00	1.50		8.00	Boron Added
M-50	4.25	4.00	1.00			
M-52	4.25	4.00	2.00			
M-54	4.25	4.00	3.00			
M-56	4.25	4.00	4.00			

Tungsten Series	Analysis (Percent)				Notes
Symbol	Tungsten	Chromium	Vanadium	Cobalt	
T-1	18.00	4.00	1.00		
T-2	18.00	4.00	2.00		
T-3	18.00	4.00	3.00		
T-4	18.00	4.00	1.00	5.00	
T-5	18.00	4.00	2.00	8.00	
T-6	20.00	4.50	1.50	12.00	
T-7	14.00	4.00	2.00		
T-8	14.00	4.00	2.00	5.00	
T-9	18.00	4.00	4.00		
T-12	14.00	4.00	3.00		
T-15	13.00	4.25	5.00	5.00	
T-20	18.50	4.00	4.00		

The above table shows some grades not in common use. However, there have been so many demands for an inclusive list that all known grades assigned an M or T symbol are given. Some are of historical importance only, or to be considered as intermediate steps in the development of the more popular grades.

These nominal analyses are intended only as a guide in establishing the types for identification purposes. Actual analyses are sometimes deliberately varied from the nominal and, in addition, there are well established tolerances for permissible deviations for each alloying element.

Table 1

VANADIUM, COBALT AND CHROMIUM — Within each series (the Molybdenum and Tungsten), it will be seen that the various grades differ in Vanadium and Cobalt content. Chromium gives the necessary deep hardening characteristics to all the analyses and is never varied outside the 3½ to 5 percent range. Less is ineffective and more results in difficulties, both as to heat treating and ultimate performance of the high speed steel. All analyses contain at least one percent of Vanadium, and larger amounts are used to secure greater abrasion resistance. The complex carbides formed by Carbon, Chromium, Molybdenum, Tungsten and Vanadium are very hard and it is these carbide particles which give high speed steel the resistance to abrasion, not only at the cutting edge, but also on unrelieved surfaces (as on saws and side mills) which rub on the work piece material. Cobalt is absent in the general purpose grades. Its function is to increase the "red hardness" of the steel beyond the basic red hardness provided by the Tungsten or Molybdenum content. Addition of five to twelve percent Cobalt secures increasing resistance to softening of the tool where heavy rubbing pressures in the cut or heavy continuous chips produce high temperatures at the cutting edge. This need for Cobalt in the analysis is also apparent where the cutting tool is buried deep in a cut and cooling is inadequate.

Where small, discrete chips are formed, as in most hobbing and in shallow milling, the Vanadium content is important in securing good tool life. On the other hand, heavy duty cutoff or forming tools and cutters taking long, heavy chips, will benefit from Cobalt additions as well. In some high feed rate, high surface speed hobbing applications today the advisability of using Cobalt high speed steel hobs must be carefully considered.

The Carbon content of high speed steels is not usually given in such tables of Nominal or Basic Analyses as shown on page 5, but is of great importance. Carbon percentage must be balanced with the content of alloy additions and must be closely controlled to secure optimum final physical properties. For example, Illinois Tool Works requires that Carbon be .73-.83 for M-1, .82-.86 for M-2 and .74-.78 for T-1 to secure the best properties and uniform, close control of hardness. In other analyses, the percentage of Carbon may be as high as 1.50, varying with the type.

Physical properties of tools made from various high speed steels are probably the best basis for selection of a starting analysis. These properties also indicate the possible changes that might be made in the starting analysis to secure the desired results in performance. The following table giving a few typical analyses shows general trends in physical properties. Over the years, the development of new work materials has given opportunity for better evaluation of high speed steels, but it is seldom that an evaluation of several analyses can be secured under identical operating conditions. The table represents a comparison based partly on analysis and partly on cumulative operating experience.

Symbol	Edge Toughness	Red Hardness	Abrasion Resistance	Grindability
M-2	Excellent	Good	Good	Very Good
M-3	Good	Good	Very Good	Fair
M-4	Good	Good	Excellent	Poor
M-6	Fair	Excellent	Good	Fair
M-10	Very Good	Good	Fair	Good
M-30	Good	Very Good	Fair	Good
M-36	Good	Very Good	Good	Good
T-1	Very Good	Good	Good	Excellent
T-5	Fair	Excellent	Very Good	Good
T-15	Fair	Excellent	Excellent	Poor

Order of Rating: Excellent, Very Good, Good, Fair, Poor.

SELECTION OF PROPER ANALYSIS—The comparative physical properties indicated in the preceding table are necessarily very general and based as much on actual shop and field experience as on a consideration of their basic properties. This manner of presentation can be useful in selecting material for the first run of a tool or in changing a tool material to gain improved performance. Tool failure by chipping suggests the use of an analysis with higher edge toughness. If a tool fails by burning, the use of a tool with higher red hardness should be considered. If the failure is caused by wearing away, a material with high abrasion resistance may prove more economical.

Cost also affects the material selection problem. Different kinds and sizes of tools may vary widely in the ratio of material and labor cost that together make up the total cost. The overall economics of a relatively small complex tool with a high ratio of labor cost to material cost is quite different from that for a tool involving a considerable weight of high speed steel.

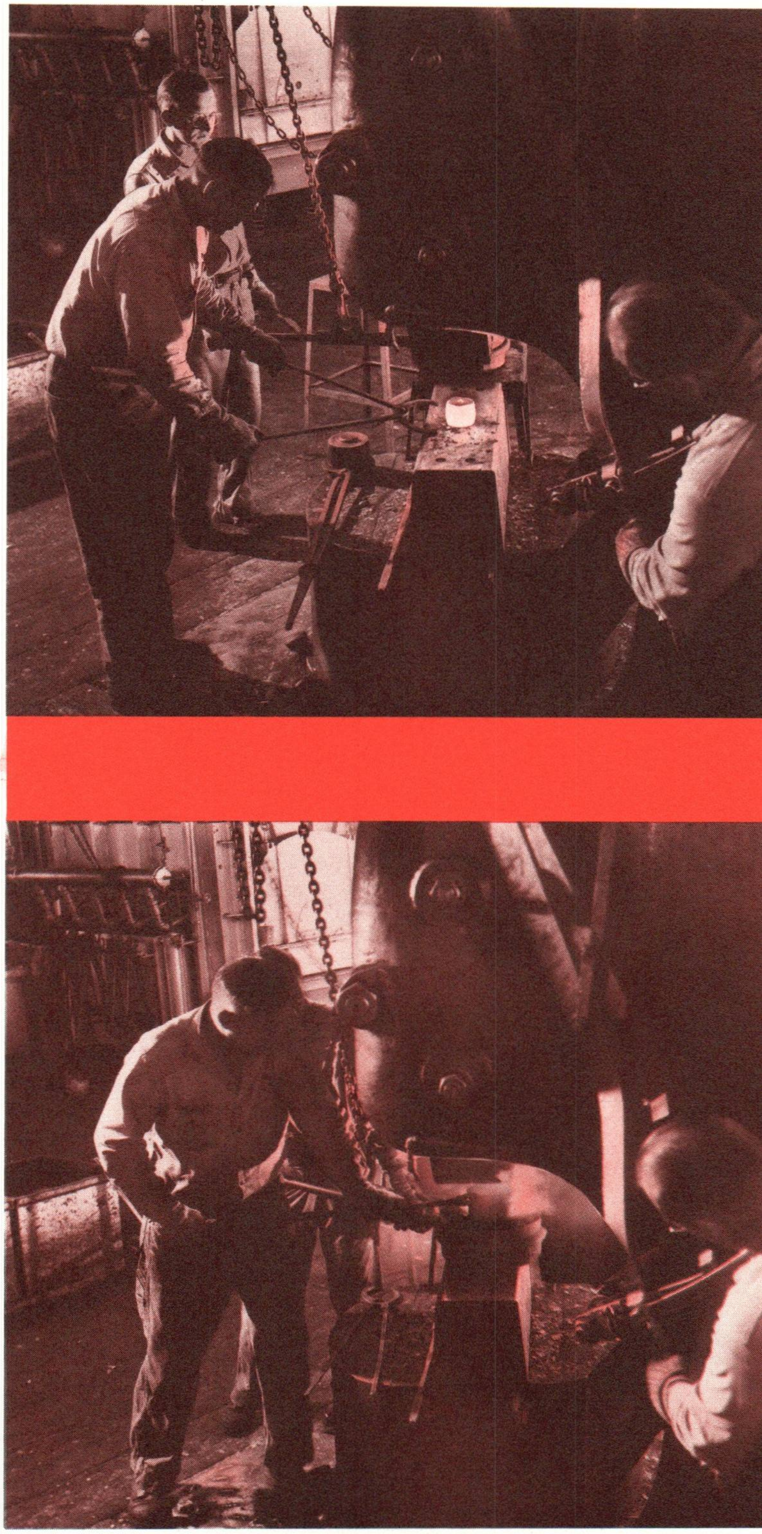
RELATIVE GRINDABILITY – Relative grindability is also of importance to the customer because tool sharpening costs are increased when grindability is poor. Grindability also affects initial tool price, because use of some of the higher alloy analyses increases the cost of tool manufacturing. The specification of a tool material that is more difficult to manufacture must presume a large increase in tool life to compensate for the increased tool manufacturing cost.

So many factors enter into tool material specifications from the standpoint of cost that it is wise to consult with the manufacturer before selecting an unusual analysis. Some of the less common materials are difficult to obtain in certain sizes, and availability must always be given consideration. Extended deliveries sometimes prevent the use of a material, whose properties appear interesting, because production schedules must be met.

FORGING –When the problem of tool steel selection has been decided, fabrication begins. At Illinois Tool Works, metallurgy is a prime consideration in every stage of tool production to assure maximum performance. Complete laboratory, testing and forging facilities together with the best types of heat treating equipment permit precise metallurgical control of finished tool characteristics.

Almost all tools are produced from blanks forged in the Company's own forge shop. Experience has shown that no high speed steel blank is in its best condition unless it has received sufficient working to break up and evenly distribute the carbides in an homogeneous manner. Bars of small cross-section may receive sufficient working at the steel mill to reach a satisfactory structure, but in general, the use of individual forgings is necessary to get the best results for medium and large size tools.

Good forging procedure starts with the selection of the proper size billet so that reduction will provide adequate working of the blank. For maximum strength, the material must be worked under the hammer to provide flow lines in the blank that are transverse to the plane or planes of greatest stress. The carbide network in the billet must be broken up and the carbide uniformly distributed. Structural control of forgings, such as shaper cutter blanks, is particularly important to insure maximum strength and cutting ability. Forged blanks are annealed following the forging process to obtain the desired structure, to relieve stresses and bring the material to the desired hardness for machinability.



F. Upset forging (above) preparatory to die forging operation (below). Blank being formed is for shaper cutter.

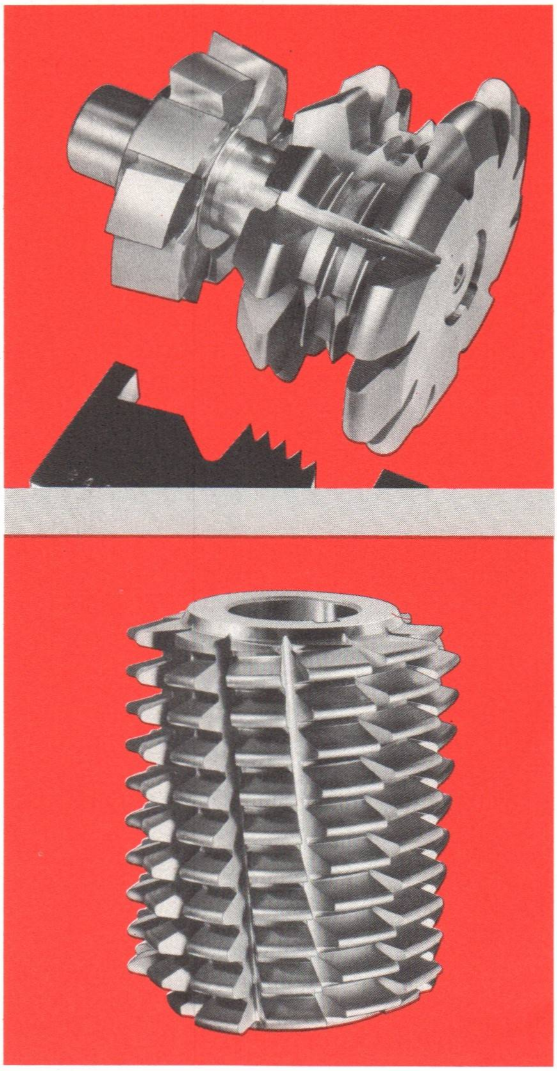
HEAT TREATMENT—The ability of a cutting tool to do its job at the lowest cost depends more on final heat treatment than on any other single factor. The heat treatment of high speed steel cutting tools is not a process that can be simply specified or controlled. Every slight variation in analysis influences the temperature, time and conditions of heat treatment. Shape, size and mass of tools must be considered. The application of each different tool must be well understood and a heat treatment used which will make that tool best for the job it has to do. At Illinois Tool Works the answers to these problems are found in many years of highly specialized tool heat treatment experience.

Unground form relieved cutters have taken over many jobs which for years were limited to ground form cutters. To consistently hold form dimensions to the close tolerances which have enabled unground cutters to be competitive with, and in many cases completely replace, ground form cutters is an achievement where metallurgy plays a large part. Illinois Tool Works Certified unground gear hobs, as one example, represent the results of years of experience in the selection of steels which will not only give the best in cutting life, but also have uniform predictable behavior in heat treating so that close form tolerances can be maintained. Unground form cutters require refinements in processing techniques even beyond those needed for ground cutters. For instance the surface condition is of prime importance as well as the base metal condition. This requires that salt baths, for example, be regularly checked for contamination and cyanide content. Illinois Tool Works makes these checks every day to ensure a constantly high level of cutter performance.

Salt bath hardening is used for all high speed steel cutting tools unless very unusual conditions must be met. Both salt bath and controlled atmosphere furnaces are available to take care of the wide variety of steels, the many diverse types of products to be hardened, and the extreme size range represented in standard and special tools. The many process operations such as annealing, normalizing and stress relieving require much auxiliary equipment and just as close metallurgical control as the final operations in hardening and tempering.

Quality Control of high speed steel hardening requires not only good furnaces but extremely accurate equipment for holding the desired temperatures, atmospheres, salt conditions, etc. Such controls are one of the principal reasons why Illinois Tool Works is able to give the best metallurgical treatment to every tool.

Cleaning by washing or blasting is often performed between heat treating operations to prevent residue of a previous treatment from pitting the work or interfering with subsequent operations. This is particularly true of salt bath treatments. If cleaning is slighted, serious consequences may appear at a later time. This danger requires that washing and blasting operations be carefully supervised.



G. Unground form cutter (above) and gear hob (below). Tools such as these are specialties at Illinois Tool Works, requiring constant care from material selection to heat treatment to predict and compensate for form distortion and to retain favorable surface as well as base metal condition.

METALLURGICAL INSPECTION—Finally before tools are released for the finishing operations they are checked to assure that they have responded to heat treatment as specified. The metallurgical laboratory is a final check on the heat treating department.

In addition to rigid control over heat treating equipment and techniques Illinois Tool Works makes use of standard Rockwell, Superficial Rockwell and Tukon hardness testers. However, hardness alone is not a sufficient criterion of quality. There are many factors which influence the performance of cutting tools that can only be determined by complete metallurgical inspection. Among these are the completeness of tempering, the presence and extent of decarburization or carburization, the determination of austenitic grain size, and the investigation of the structure for segregation and banding. In addition to the more conventional techniques of polishing, etching and microscopic examination Illinois Tool Works also uses an electrical etching and polishing technique in conjunction with microscopic examination. Constant checking of production tools by this electrical etch and polish equipment maintains quality in these respects. This has the advantage of being nondestructive and fast, thus permitting a constant, continuing check on large volumes of work to make sure that all cutting tools comply with rigid metallurgical standards. Thorough tests make certain that the heat treating process has produced the desired result before further work is done on the tool. In addition, test blanks are put through the regular processing procedures at frequent intervals to ensure that all operations are contributing their share of quality to the finished tool.

Very large forgings receive sonic inspection for defects before manufacture proceeds and all large forgings receive careful inspection, especially in the bore, for possible flaws after the turning and boring operations. In addition, Magnaglo and Magnaflux equipment is used after grinding as a final inspection quality check.

HARDNESS RANGE — Illinois Tool Works prides itself on holding to narrow selected hardness ranges for all cutting tools. This requires close control of chemistry in the high speed steel. Whereas a two point Rockwell "C" range (for example 64-66 RC) is considered normal practice, Illinois Tool Works maintains a one point range as standard practice. This is made possible by purchase of full heats of material, insistence upon rigid steel analysis specifications, trial runs on each heat and close control of the hardening and tempering techniques.

I. Each cutting tool is checked after heat-treatment for precise hardness. Illinois Tool Works maintains one point tolerance range as standard practice.

J. Electro polishing and etching permits metallographic inspection of finished tools.

K. Preparing samples
tion.

WHAT HARDNESS?—The Rockwell "C" scale is somewhat deceptive in that a two point range gives the impression of close control, and it should be logical to assume that the physical properties of high speed steel at 64 or at 66 would not be sensibly different. This is not true. For example: the abrasion resistance of the same high speed steel is much greater at 66 Rc than at 64 Rc. Since Illinois Tool Works insists on a carbon content sufficient to consistently secure maximum hardness for a given steel, and also maintains a narrow hardness range, optimum properties can be developed for all types of cutters and to suit specific applications.

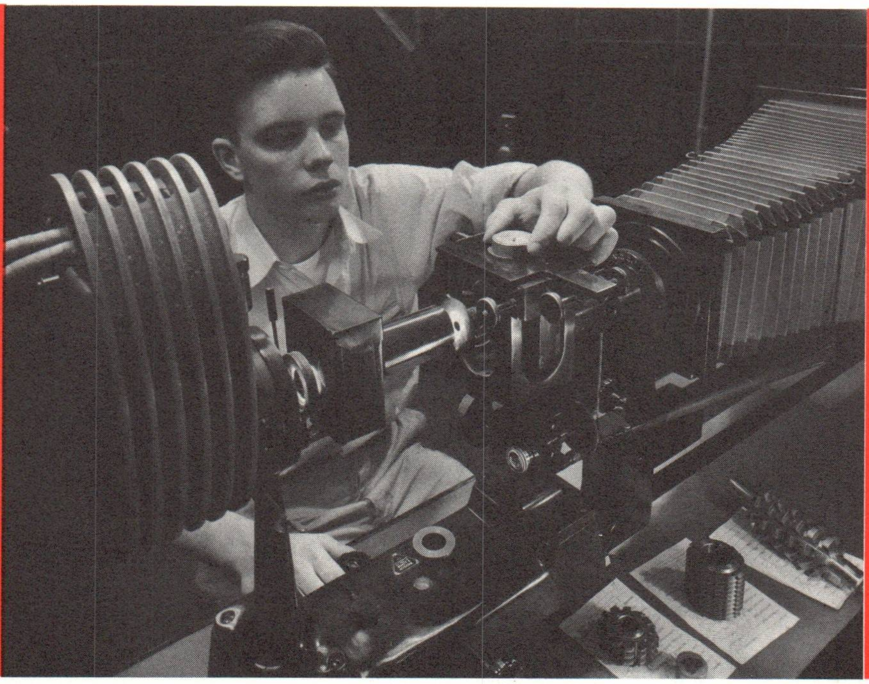
In general, the policy at Illinois Tool Works is to develop the maximum potential of a given high speed steel by holding to the high limit on hardness. In the case of the premium grades such as M-3 and T-15, the additional cost is not recovered in greater tool life unless they are brought to maximum hardness. For example: M-1 and M-2 should not be less than Rc 64.5, M-3 and M-4 not less than Rc 65.5, and T-15 not less than Rc 66.5.

Where a hardness less than the maximum (for a given high speed steel) is desired it can be obtained by additional tempering or by hardening from a lower temperature. The resulting final Rockwell hardness can be the same from either method but greater toughness is obtained by the second method. This is given only as one example to show that a hardness specification alone may be inadequate to assure the desired performance.

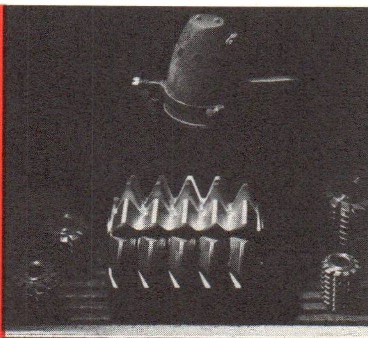
GRAIN SIZE—A major concern in the manufacture of superior high speed steel cutting tools is securing a fine austenitic grain size in the finished tool. Once a heat of steel is poured, no heat treatment, chemical, or thermal process will refine the grain size. In fact it requires unusual experience and equipment to prevent an undesirable growth or enlargement of the grain size during processing. Constant vigilance in checking furnace and salt bath conditions, accurate temperature measurement and quickly responsive controls, plus long experience in the individual requirements of each particular tool, are combined to an unusual degree at ITW to prevent undesirable grain growth during hardening.

allographic inspec-

L. Tool steel specimens are examined microscopically for uniformity.



M. Magnaglow inspection to detect heat treat cracks or material flaws and grinding checks or cracks.



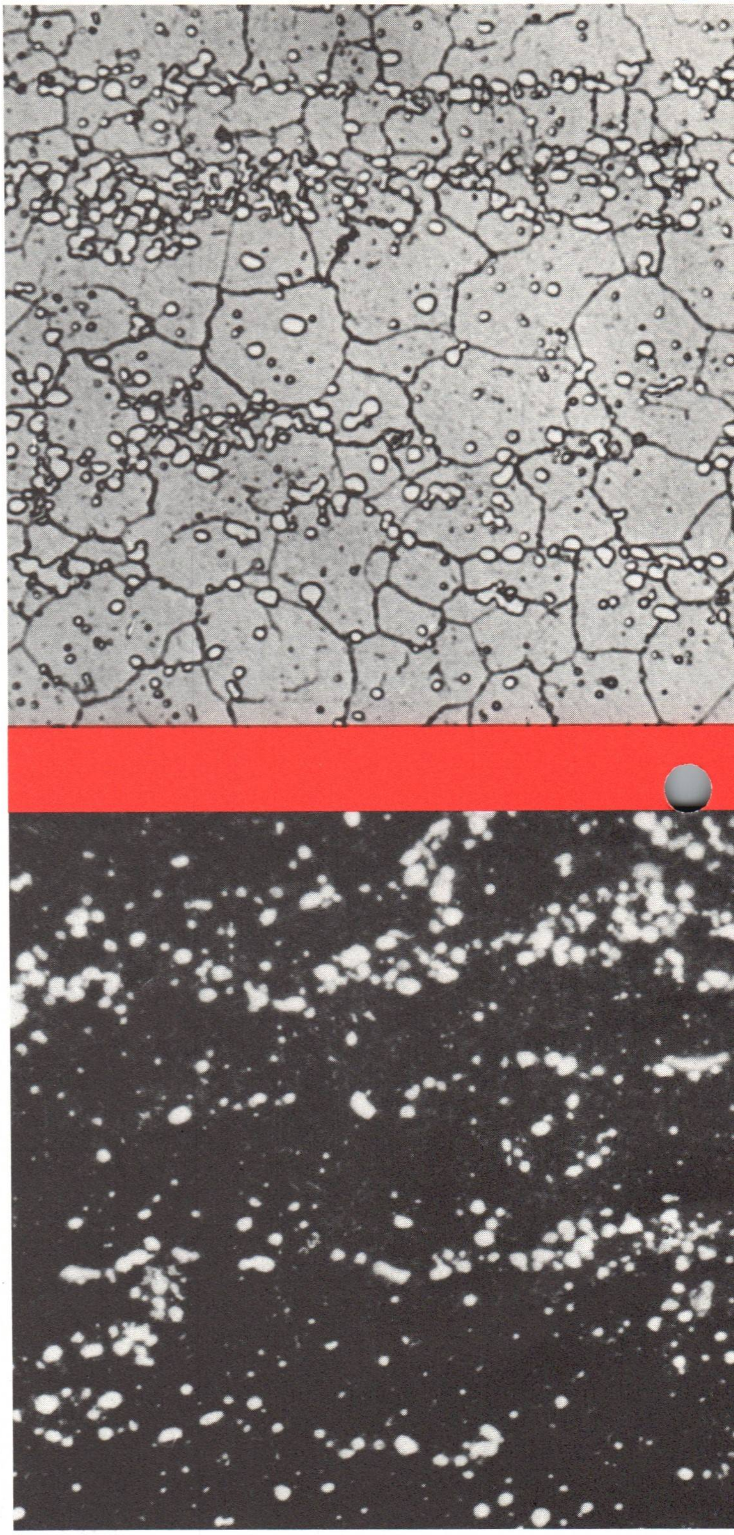
N. Chemical analysis is an important step in complete metallurgical control.

Whereas nothing can be done by heat treating to refine the grain size, mechanical working and reduction in stock size by rolling, drawing or forging will do so. Small bars as they are received from the steel mill have been reduced in size by rolling to such an extent that the grain size is satisfactory. For large cutters, forging is the only way to obtain best possible grain size. In small cutters the average grain size number should be not less than 12 and the medium or large size cutters not less than 10. It is unfortunate that some standards have been set which disregard the fact that in very large cross sections an average grain size of 12 to 13 cannot always be secured, much as it is desired.

CARBIDE SIZE AND DISTRIBUTION—The hard carbide particles in high speed steel must be small and uniformly distributed. To attain this goal, rigid acceptance standards for all purchases of high speed steel bars and billets must be maintained. Figure 1 shows the actual standards (by range size) used by Illinois Tool Works in accepting incoming steel. When carbide particles are not uniformly distributed throughout the bar or billet, but are instead concentrated in clusters in certain areas, the condition is spoken of as excessive "segregation".

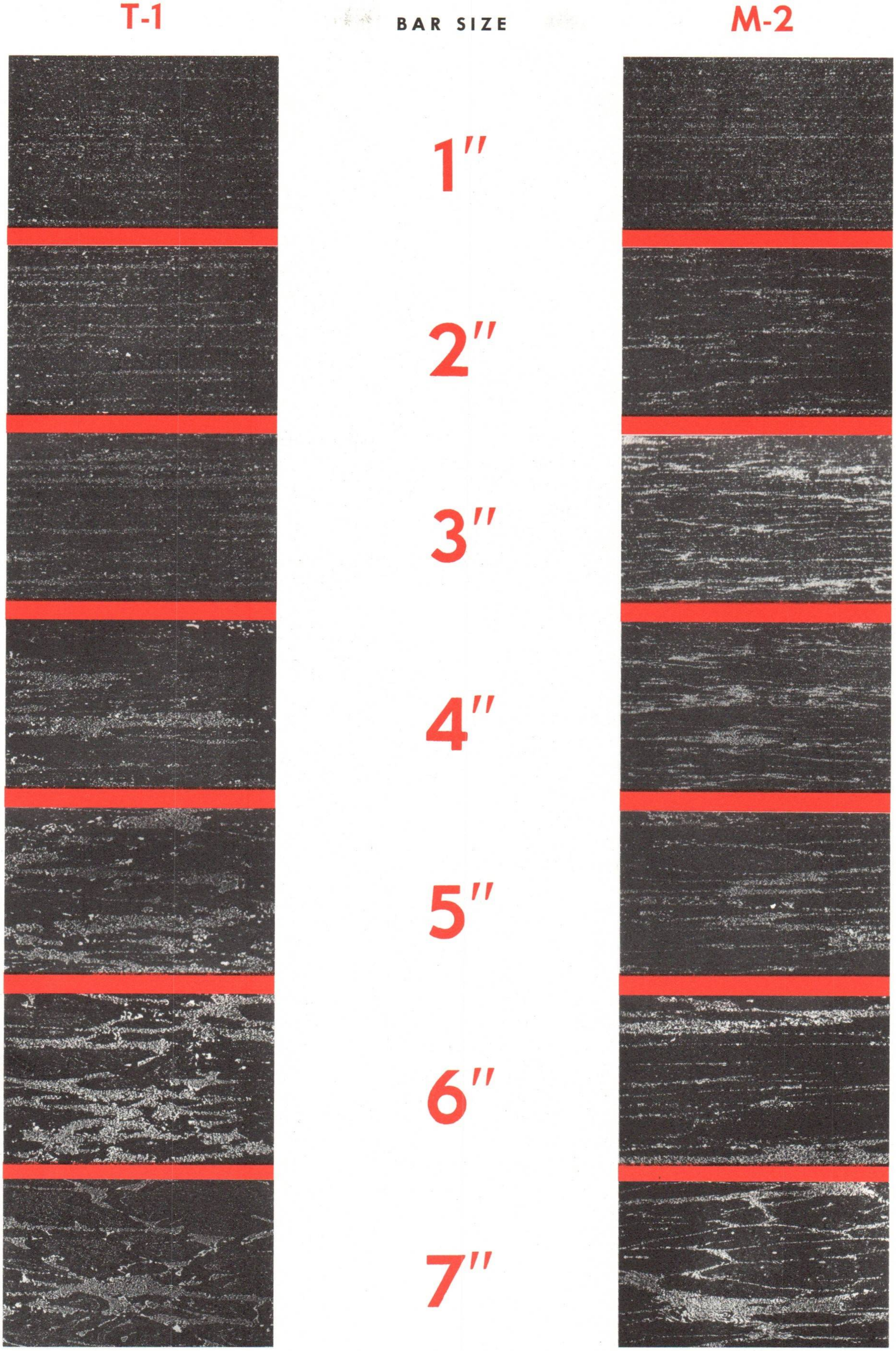
It is equally important that the carbide particles be surrounded by the body steel or matrix instead of being grouped together in stringers, layers, or a coarse network formation. When the carbide particles are closely grouped in clusters, layers, or a coarse network they form zones of weakness in a cutting tool which may result in early failure. The same photomicrographs Figure 1 show the maximum allowable carbide concentration in such layers or network for incoming steel at Illinois Tool Works.

It will be noticed that more latitude must be allowed on large cross sections as received; however, these larger cross sections are from billets which are later forged into finished cutting tools. By the proper selection of the billet size for a given finished tool and the use of skillful forging techniques, Illinois Tool Works secures a fine grain structure, well dispersed carbide distribution and fine uniform carbide network in all finished tools.



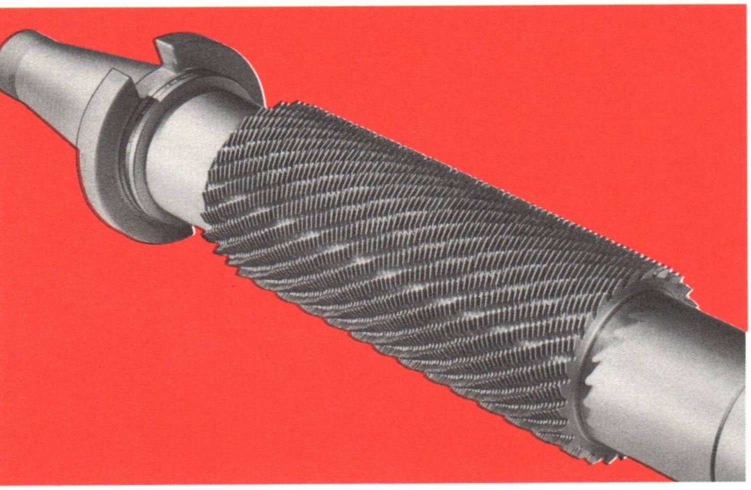
O. Grain structure (top) of M-2 steel, for 3" x 3" hob. Lower cut shows carbide form and distribution of same billet. Both photos at 1000X magnification.

CARBIDE FORM AND DISTRIBUTION STANDARDS



50X MAGNIFICATION
Figure 1

SPECIAL MATERIAL FOR SAWS—Metal cutting saws require special consideration in the matter of proper grain structure for maximum performance. Illinois Tool Works uses only Cross-Rolled high speed steel sheet stock for saws. Stock processed in this way has maximum resistance to breakage due to the fine grain and oriented structure obtained by rolling. Saws are never cut from bar or billet stock except with the customer's consent in order to fill some emergency demand. Cross-Rolled stock is either on hand or readily available in the popular grades of high speed steel, but in some analyses it must be rolled to order.



P. Gang of 92 saws for slotting spacing bars. Saws require special material as well as heat treatment to maintain strength at cutting edge and guarantee flatness.

SULPHURIZED STEELS—High speed steels have a low machinability rating and to overcome this difficulty Sulphurized high speed steels have received increasing attention since 1953. The chief gain to the user of cutting tools is in the consistently better finishes that can be achieved on the form relieved (backed-off) type of cutter. There is general agreement among users that Sulphurized high speed steels are equal in performance to the un-Sulphurized. In spite of this there has been a natural disposition at ITW to proceed cautiously and the change to Sulphurized grades is a gradual one.

The successful use of Sulphurized steels depends on the establishment of rigid specifications for the size, shape and distribution of the sulphide particles. The company exercises great vigilance in close metallurgical control in this respect to secure satisfactory cutting tools.

SECONDARY TREATMENTS *(To change the base metal characteristics)*—All new developments and suggestions for changes in the metallurgical field where the performance of cutting tools is at stake are carefully investigated. To date, despite much testing, no clear cut gain is apparent through the use of any available secondary treatments. This of course assumes the high speed steel is of the best quality and properly hardened and tempered.

SURFACE TREATMENTS *(To change the surface characteristics)*—Under certain conditions surface treatments will improve the life of cutting tools. But, none will compensate for low hardness of the base metal, high speed steel of poor quality, or improper hardening and tempering.

Three surface treatments have stood the test of time—Nitriding, Oxide Treatments and Vapor Blasting. These can be used singly or in combination, as where a Nitrided tool is subsequently Vapor Blasted. Nitriding and Steam Oxide treatments, since they are applied at tempering temperatures, have the effect of an additional tempering cycle. However, at Illinois Tool Works all high speed steel hardening involves the use of at least two tempering cycles whether surface treatments are used or not.

OXIDE TREATMENTS—A blue or black oxide can be produced on high speed steel tools by heating them in the presence of an oxidizing agent. This may be done in a chemical bath but Illinois Tool Works uses the well known Steam-Homo process. In this case tools are heated to the 1,000°F-1,050°F range in the presence of steam. The resulting black oxide has an attractive appearance and has definite lubricant retaining properties.

The oxide surface also has a slipperiness which assists chip flow and helps to prevent "galling" or welding of small particles to the cutter surface. Beyond the fact that the tools are at temperature for about an hour and thus receive the equivalent of an additional tempering cycle there is no metallurgical effect, and there is no penetration of the surface as in the case of Nitriding. The additional tempering, however, is felt to have a beneficial effect in reducing surface stresses caused by grinding. There has been some objection to the use of an oxide treatment on such form relieved cutters as hobs because it is more difficult to determine the amount which must be removed in sharpening.

VAPOR BLASTING—This is an abrasive blasting process using a water suspension of very fine abrasive powder, usually about 1200 mesh. It in no way changes the metallurgy of the tool, but does produce a fine matte finish which promotes spreading and adherence of the coolant or lubricant. It refines the finish to some extent, and removes minute grinding burrs and "feather edge" on cutting edges. The fine grey finish is attractive and this alone accounts for its use on some occasions. Used after Nitriding, it removes the less attractive mottled finish produced by the casing salts and also produces a better surface for lubricant retention. It can be repeated any number of times, as tools are sharpened, without detrimental effect.

NITRIDING—This process is sometimes referred to as Cyaniding and sometimes as Nitriding. This confusion stems from the fact that the case is generally considered to be the product of both Cyaniding and Nitriding. Often the process is "glamourized" by the use of coined or trade names which add nothing to its virtues.

Nitriding is carried out by immersing the cutting tools in a molten bath, consisting principally of a mixture of sodium cyanide and potassium cyanide salts, which is held at a temperature in the range of 1000°F to 1050°F. The result of this process is a case or surface layer on the cutting tool (usually not over .001 in depth) which contains a combination of nitrogen and carbon and is appreciably harder than the maximum hardness which can be obtained in the fully heat treated high speed steel. The casing salt produces a surface with high abrasion resistance and good lubricant retaining properties but more brittle than the base metal. This leads to the conclusion, proved by practice, that Nitriding is definitely advantageous where untreated tools are failing by abrasion. On the contrary Nitriding should not be used where untreated tools are failing by chipping. Where the tools may be subject to chatter, vibration and heavy impact loading on the cutting edge each job must be considered on its own merits.

In general the depth of case is related to the Nitriding time and it is usually specified and controlled by giving the "time at temperature." In some cases the "time" might be as little as 10 minutes and in some cases as high as 60 minutes. 20 to 40 minutes in the salt bath at the correct temperature is the usual range employed for cutting tools. Nitriding lowers the shock resistance of tools (to impacts) and, therefore, in the absence of experience with similar Nitrided tools, customers should refer this decision and the determination of the proper case depth to the manufacturer.

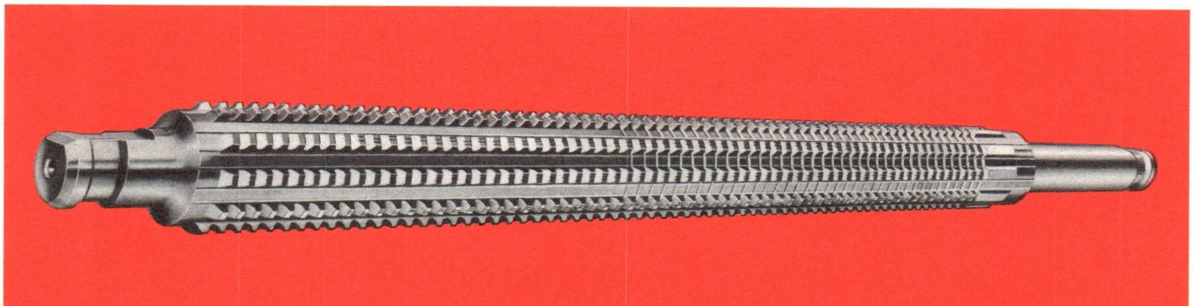
Different types of tools and the same type of tool for different operating conditions require different approaches to the use to Nitriding. Unground hobs, multiple thread milling cutters and form relieved cutters would be Nitrided directly after hardening (before grinding is done). A ground form hob or shaper cutter, however, would be Nitrided after the form is ground but before the final sharpening. A profile sharpened milling cutter, on the other hand, might be Nitrided directly after hardening, at some intermediate point in the sequence of grinding operations, or as a final operation. The choice in this case will depend upon whether all surfaces are to receive the Nitride case or only certain selected surfaces are to have a case.

Sometimes customers re-Nitride tools after each sharpening. This may be satisfactory in some cases but may also lead to an undesirable increase in case depth on the surfaces which are not ground each time the cutter is sharpened.

OPERATING—The choice of feeds and speeds for cutting tools is usually beyond the control of the cutting tool manufacturer. This area is a fruitful one to investigate for profits in securing lower unit cost per piece machined. The gains to be secured in this area are frequently greater than those possible by up-grading the tool material.

FEEDS —One of the most frequently encountered reasons for short life of multi-edged rotary cutting tools is taking too small a chip load per tooth. This causes excessive abrasive wear of the cutting edges. Since chip load per tooth is an indirect expression of Table Feed, an increase in chip load per tooth represents a direct reduction of machining time. As a general observation it can be stated that many cutters are not being operated anywhere near their capabilities as regards chip load per tooth.

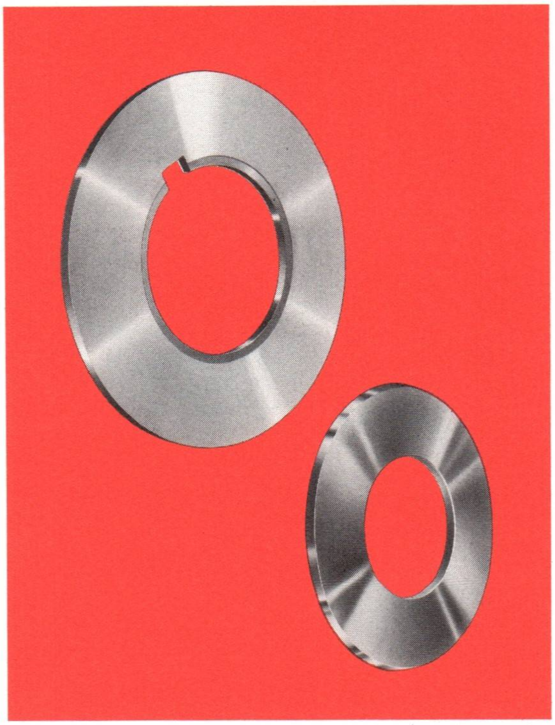
Q. Spline broach. Broaches are often nitrided and vapor blasted. Liquid Nitriding improves surface hardness for abrasion resistance. Vapor blasting improves lubrication retention.



SPEEDS —The life of any cutting tool, regardless of tool material, is lowered by an increase in speed (surface feet per minute) and vice versa. Establishing the cutter speed which gives the lowest total machining cost per piece requires finding the proper balance between the operating cost of the machine tool and the cost of the cutting tools. An analysis of this type may show that cutting tools are not being expended at a fast enough rate to achieve the lowest overall cost per piece produced. As an example, a higher cutter surface speed, which increases production, through higher table feed rates, shortens the cutter life, yet may give the lowest total cost.

This approach to establishing optimum cutter life is made necessary by the present high ratio of machine overhead and labor costs to the cost of the cutter. It is in fact, not peculiar to machining alone, but equally applicable to grinding operations.

An often repeated question put to cutting tool manufacturers . . . "How fast should I run this cutter?" . . . pre-supposes that an individual cutter has some inherent best speed as a definite physical characteristic. This is not true and the best speed for the cutter must be selected on the basis of making it the best speed for the complex process of which the cutting tool is only a part.



R. Slitters are made of carbon steels of various alloys as well as H.S.S., and require precise metallurgical control keyed to a specific application to secure optimum performance.

HELPFUL HINTS FOR LONGER TOOL LIFE —
What to consider when tool failure is—

- **A.** By Abrasion
  - I—Tool Material and Metallurgy
    - a—Use maximum hardness for cutting tool
    - b—Nitride
    - c—Use a high speed steel with greater abrasion resistance
  - II—Design
    - a—Increase relief
    - b—Use fewer teeth to increase the chip load per tooth
  - III—Operating Conditions
    - a—Decrease cutting speed
    - b—Increase chip load per tooth
    - c—Filter the coolant
    - d—Use coolant with greater lubricating value
- **B.** By Chipping
  - I—Tool Material and Metallurgy
    - a—Eliminate Nitriding (or use a lesser case depth)
    - b—Use a high speed steel with greater edge toughness
    - c—(Sometimes) Decrease tool hardness
  - II—Design
    - a—Decrease rake
    - b—Decrease relief
    - c—Design for minimizing impact loads on teeth
    - d—Use chamfers (or radii) on sharp corners
  - III—Operating Conditions
    - a—Increase cutting speeds
    - b—Improve finish on cutting edges
    - c—Vapor blast
    - d—Increase overall rigidity of set-up
    - e—Decrease chip per tooth
    - f—Reduce recutting of chips
- **C.** By Burning
  - I—Tool Material and Metallurgy
    - a—Use a Cobalt high speed steel
    - b—Increase the Cobalt content
  - II—Design
    - a—Increase relief and clearance
    - b—Increase chip room
    - c—Improve chip flow
    - d—Design for smaller chips
  - III—Operating Conditions
    - a—Decrease cutting speeds
    - b—Decrease chip per tooth
    - c—Increase coolant supply to the cutting edges
- **D.** By Galling (welding of work piece particles to tool surfaces)
  - I—Tool Material and Metallurgy
    - a—Increase tool hardness
    - b—Nitride
    - c—Use oxide surface treatment
  - II—Design
    - a—Increase relief and clearance
    - b—Reduce area of unrelieved rubbing surface
    - c—Reduce width of primary lands
  - III—Operating Conditions
    - a—Remove chips from cutting zone (to reduce recutting of chips)
    - b—Reduce wobble (axial runout) of cutter
    - c—Increase lubricity of coolant
    - d—Increase chemical activity of coolant (Sulpho-Chlorinated materials)

CUTTING TOOL LIFE—Where the work piece hardness range is wide the coöperation of the plant metallurgist in holding to the low side will result in better tool life.

The cost of free machining material or heat treatment to improve machinability may be more than compensated for by increased cutter life.

On hard materials and those which have work hardening tendencies a uniformity in feed and uniform chip per tooth (minimum cutter runout) are necessary for success.

Turned surfaces on medium and high carbon work pieces may be heated (if turning tools are dull) sufficiently to create a hardened surface layer, perhaps .002 thick, which is very destructive to hobs, shaper cutters or other cutting tools, used in subsequent operations.

When a cutting tool has dulled appreciably, further wear or break down proceeds at a constantly increasing rate. A small increase in number of pieces machined beyond the optimum will result in disproportionate cutter wear. Establish maximum cutter wear land width and insist on sharpening at this point.

Face the fact that some work piece materials in use today require very low cutting speeds, in some cases as low as 10 surface feet per minute.

Initial chipping of the cutting edges may be obscured by wear occurring later. Examine early (with a glass) for indication of chipping.

Climb milling usually increases cutter life, except where the surface of the workpiece is hard or scaly.

Unexplained failures sometimes result from accidental magnetization of cutting tools. (Test with a paper clip suspended near the tool by a long piece of thread.) If magnetized, cutter may clog with chips or constantly recut chips.

Allowing cutters to dwell at the end of a cut causes rapid wear, and may work harden the part material.

Cutter runout, due to improper sharpening or poor mounting, can cause short life because all teeth are not taking equal loads. Also those teeth cutting only thin chips or just rubbing on the work surface can cause work hardening which will hasten the failure of those which are doing all the work.

Do as much machining as possible while the work piece is in a favorable metallurgical condition. Review process sheets to get the best sequence of operations to favor cutter life. Illinois Tool Works can build corrections for heat-treat distortion of the part into many types of tools.

Chatter or vibration is a prime source of poor cutter life and a principal limit on production rate. Larger cutter arbors, well fitted bearings, reduced cutter overhang and rigid fixturing will increase cutter life and permit greater production rates, even on old equipment. Proper cutter design for specific operating conditions will frequently reduce chatter, but it is far better to minimize vibration problems by increasing overall rigidity. Because of the many operating variables, cutting tool designs which overcome chatter in one application may not do so in other environments.

Failure of a cutter by breaking out large sections or complete fracture are rare. When it occurs the cause can be traced to such factors as:

Accidental use of too high feed rate
Accidental use of the rapid traverse
Failure to use a key in the arbor
Excessive play in gibs or spindle
Use of long, slender, unsupported arbor
Failure to tighten nuts, stops, etc.
Accidental contact with machine, vise or fixture

On large form relieved cutters, especially on coarse pitch hobs, poor flute grinding techniques may produce grinding cracks which cause catastrophic failure.

Catalogue stock cutters are general purpose tools. They will do an excellent job in a wide variety of applications. In many cases, however, cutters engineered for the specific application by Illinois Tool Works will do a better job.

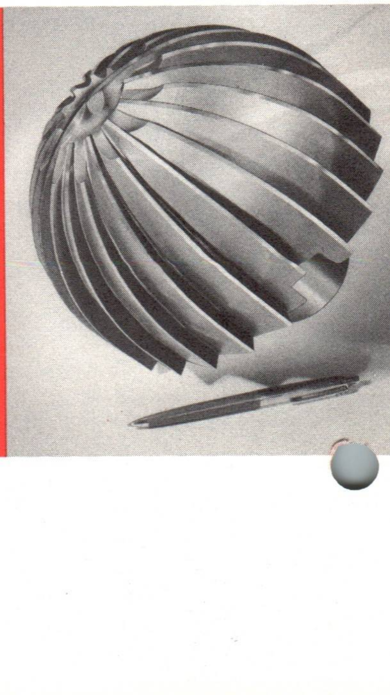
Rotary shears, often called slitters, require special metallurgical attention because of their unique cutting action. For the most part, slitters should be ordered to do a specific job. It is economical to consult with the slitter manufacturer at the time of ordering, giving full particulars as to the material to be cut, and the equipment to be used. In this way, proper steel selection and controlled heat treatment will guarantee optimum performance.

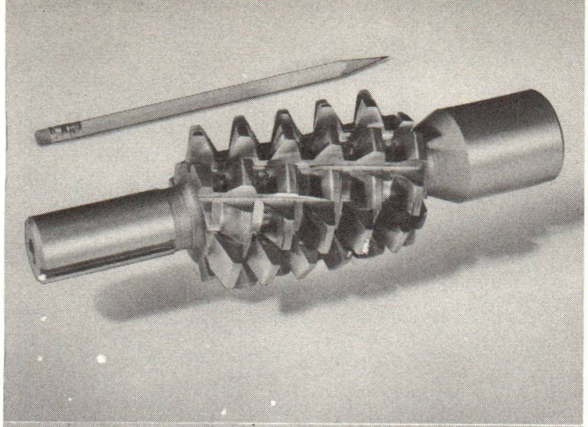
To get the most cutter life for your money, send the part print as well as the cutting tool specifications when ordering special tooling. Supply the details showing the nature of the operation. Remember that the more the tool designer knows about your job, the better and more economical cutting tool you get.

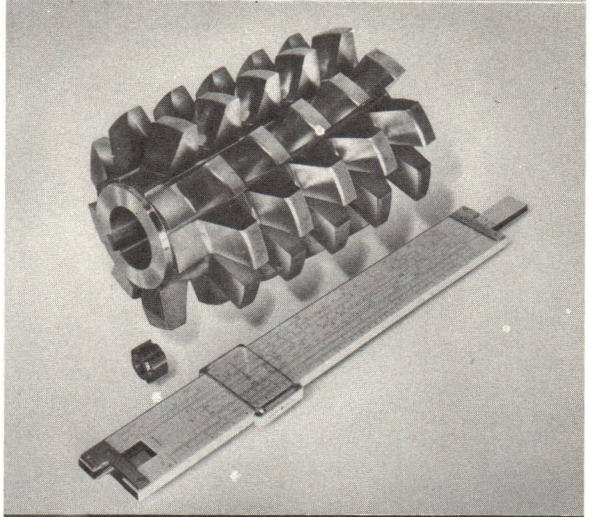
Summary

In the design and production of metal cutting tools, metallurgy, which includes the processes of material selection, forging and heat-treatment, is the prime ingredient.

1. Material selection is frequently the key to low-cost, high performance tooling and is determined by the type of material to be cut and the conditions of the cut.
2. General purpose HSS analyses perform adequately on the vast majority of applications, however, selection of premium HSS will sometimes lower the cost of tooling as well as improve performance.
3. Edge toughness, Red hardness, Abrasion resistance and Relative grindability are factors which govern material selection.
4. Forging and its effect on the carbide network and grain flow provides the tough cutting edges and structural strength of the tool.
5. Pin-pointed heat treatment is by far the most important element in metallurgical quality control.
6. Surface treatments may improve performance of the cutting tool and must be determined by the application.
7. Selection of feeds and speeds for each cutting tool is not a magic formula nor inherent in the tool. The application and equipment determine these variable factors.







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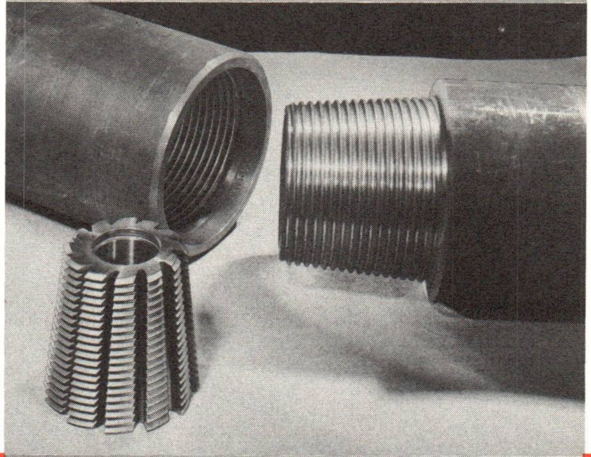

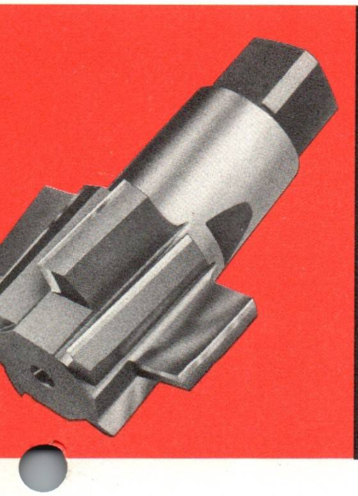

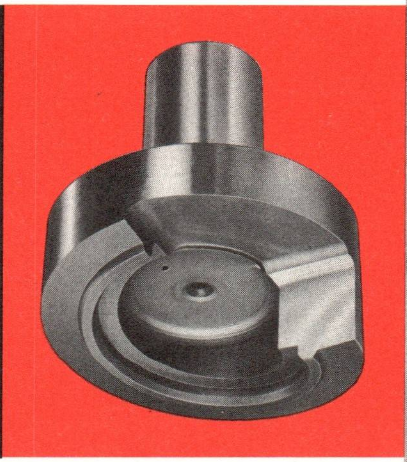

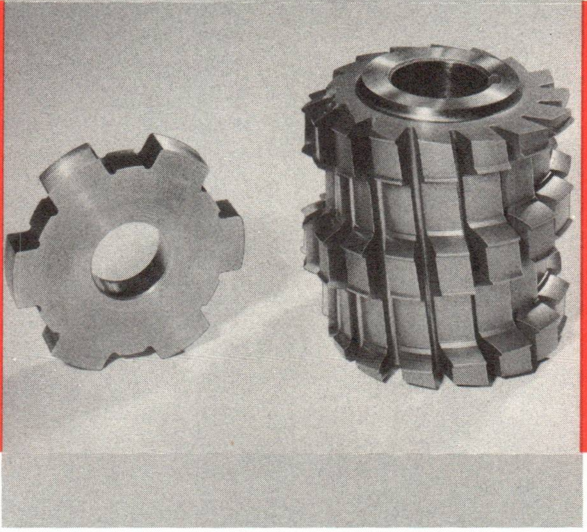

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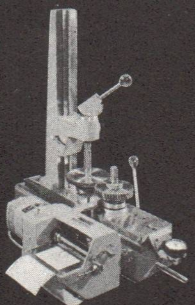

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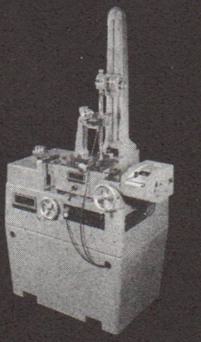

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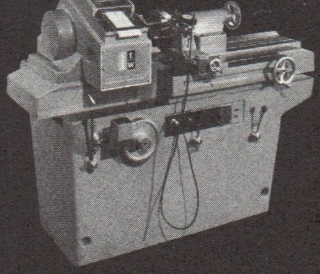

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